THE SWITCH ON CHARACTERISTICS AND NOISE OF PULSED READ IMPATTS IN Ku BAND

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ABSTRACT

The switch on characteristics and interline noise of free running, phase primed and phase locked pulsed Read Impatts have been studied in detail. The results obtained have been compared with high efficiency transferred electron devices operating in the same frequency range and very significant differences noted. Although the majority of the work has centred upon the study of high power high efficiency single drift devices some results are presented for double drift devices. The rapid switch on characteristics show that the Read Impatt is ideally suited to short pulse fast rise time applications over broad temperature ranges. These characteristics of the device are explained by existing theoretical device models, and it is shown that in the phase primed mode the residual interline noise is dominated by a small random pulse to pulse starting phase error.

INTRODUCTION

In an ideal pulsed oscillator the frequency spectrum consists of a series of sharp lines, referred to as Fourier lines, spaced apart by the pulse repetition frequency with $\mathrm{sinc}^2 x$ amplitude. For this ideal case to be achieved there must be perfect coherence between the starting phase of all of the pulses of RF energy. In practice this will not be achieved and there will be a degradation of the observed spectrum. Thus from a detailed examination of this spectrum it is possible to deduce information concerning the starting conditions in the oscillator. In this paper we shall consider three starting conditions; the two extreme cases of free running and phase locked oscillators and the intermediate case of phase priming[1] where the power injected into the oscillator is insufficient to cause phase locking. Now since in any pulsed oscillator the development of the device admittance between small and large signals determines the switch on characteristics the conductance change determines not only the RF risetime but also the magnitude of any delay and jitter after the application of the bias pulse. In addition the susceptance change will determine the shift, if any, between the start frequency of the oscillator and the final stable operating frequency. As the paper proceeds we shall consider the basic design of the device, the characteristics of free running oscillators and then phase controlled oscillators.

DEVICE DESIGN AND FABRICATION

The single drift devices were all of the high efficiency Read type having the Hi-Lo profile and employing both Schottky barriers and grown p^+ regions to define the junction. A typical profile is shown in Figure 1. In all cases the epitaxial face contact was a stable Ti/Pd/Au metallisation and an ohmic contact technology employing In/Ge/Au was used for the contact to the substrate face. As a precursor to the growth of true double drift Read structures double drift uniformly doped devices have been assessed, employing the same contacting technology as the grown p^+ junction single drift devices. In all cases the doping profiles were optimised for operation in the pulsed mode at duty cycles of up to 25% and current densities two or three times greater than those appropriate to CW devices. Pulse widths were normally in the range 25 ns to 1μs.

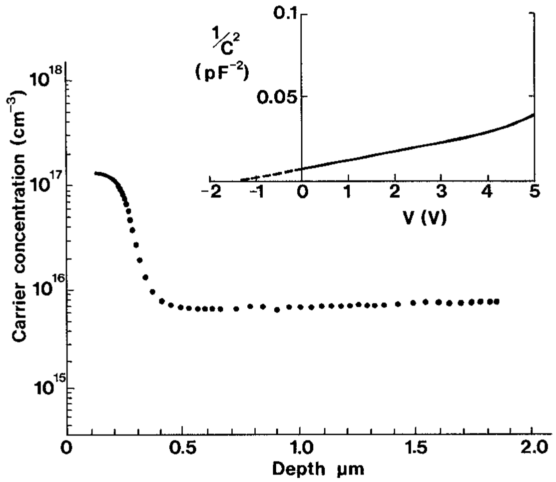


Fig. 1. Doping profile of a p^+-n Read Impatt

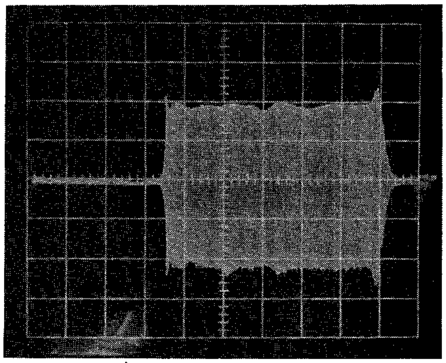
In order to extract the mean power efficiently from these devices an integral heatsink technology has been employed using a gold heat sink for both single and multimesa structures. The devices were then bonded ultrasonically into suitable low parasitic reactance packages for subsequent inclusion in either waveguide or microstrip circuits.

The single drift Read devices gave the highest efficiencies with 26% being achieved at peak power levels of 4W throughout both X and Ku bands. Peak powers of 7.5W at 22% efficiency have been obtained at upper Ku band. Being uniformly doped the double drift devices were less efficient with peak powers of 10W and efficiencies of 18% being achieved in low Ku band. Resonant cap circuits have been used almost exclusively for device assessment since they provide ease of operation over a broad range of frequencies.

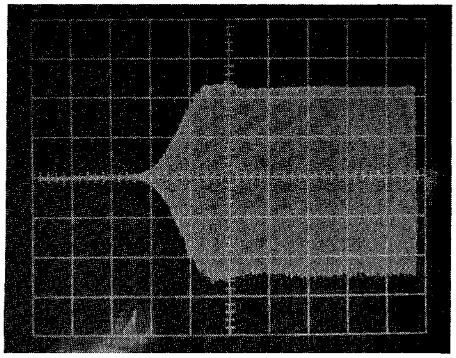
FREE RUNNING OSCILLATORS

Since we are considering free running oscillators, in which the bias current is pulsed, in the absence of a synchronising signal there can be no pulse to pulse coherence and it is impossible to make any measurements of spectral purity. We shall thus only consider the overall RF envelope. Of the two classes of high efficiency two terminal microwave oscillators the Impatt diode exhibits far superior switch on characteristics to the indium phosphide TEO, where switch on delays of tens of nanoseconds can be observed[1]. The switch on characteristics of the Read diode are much better and delays of 2 ns and residual rms jitters of <100 ps are typical. To achieve these fast risetimes, and not to degrade the high efficiency of which the Read Impatt is capable, we have developed a range of constant current pulse modulators in which an inductor is used as the energy storage element and a VMOS FET in shunt with the device diverts current away during the interpulse period. Using this method oscillators with overall DC to RF efficiencies of greater than 15% have been constructed which only require a 15V DC supply and a TTL trigger pulse.

Figure 2 shows the RF voltage pulse (measured using an 18 GHz sampling oscilloscope) of a 7W peak short pulse oscillator at 15.7 GHz. The extremely rapid RF risetime is evident from these photographs as is also the lack of any significant pulse to pulse jitter; the sampling oscilloscope being triggered from the trigger pulse to the modulator. These risetimes have been achieved in fixed tuned circuits over the temperature range -50 to +75^{o}C; at a fixed bias current the output power reduces as the temperature is decreased with a temperature coefficient of 0.02 dB/^{o}C.



10 nsec/div.



1 nsec/div.

Output power 7 $\hat{W}$

Fig. 2. RF voltage pulse

PHASE SYNCHRONISED OSCILLATORS

In order to achieve pulse to pulse phase coherence it is necessary to provide a synchronising signal at the start of each pulse, to control the starting phase, which may be sufficient either to phase lock or phase prime the pulsed oscillator, the degree of coherence increasing as the priming power increases. In a phase locked oscillator sufficient power (typically -10 dBc) is injected into the oscillator from the synchronising source to control the phase such that both oscillators operate at the same frequency. However in a phase primed oscillator the synchronising (or priming) power is insufficient to ensure phase locking but is sufficient to be the dominant factor in the build up of oscillations from small to large signals; and thus impresses its own phase as an initial starting phase upon the pulsed oscillator which then deviates in phase (continuously) once large signal operation takes place. Typical powers required for phase priming are much less than for phase locking (typically -50 dBc) and may be at offset frequencies of up to 1 GHz.

It can be shown[1] that if the degree of pulse to pulse phase incoherence has a small Gaussian error $\sigma\phi$ then each Fourier line is reduced in magnitude by an amount $\sigma\phi^2$ and that this power loss is observable as a white noise contribution, between the Fourier lines. The ratio of the peak of the Fourier line to this noise (measured at the spectrum centre) is called the peak to valley (PV) ratio and is given by

$$\frac{prf}{\sigma\phi^2} \text{ Hz}$$

Thus a measurement of the PV ratio can be used to determine the pulse to pulse phase error $\sigma\phi$. The essential parts of the measurement system are shown schematically in Figure 3. It is implicit in all the analysis referred to above that there is no residual jitter in the prf, and this is achieved in practice by using a crystal oscillator as the reference for the prf.

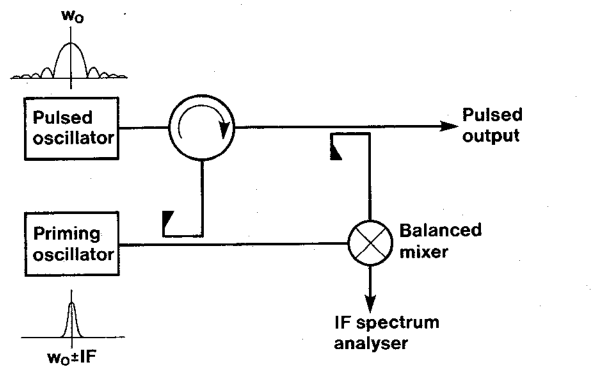


Fig. 3. Schematic diagram of the measurement system

Figure 4 shows the interline noise (expressed as the PV ratio) for both the phase priming and locking modes at an offset frequency of 30 MHz. At low priming powers the PV ratio increases as the priming power is increased as the injected signal gains control of the starting phase of each pulse. The flat portion of the curve corresponds to a residual phase error as the oscillator makes its rapid transition from small to large signal conditions. The scatter of results at the onset of phase locking is associated with the phase transients which occur at the edge of the locking band. Inside the locking band the oscillator frequency is the same as the injecting oscillator and the interline noise takes on the characteristics of this source.

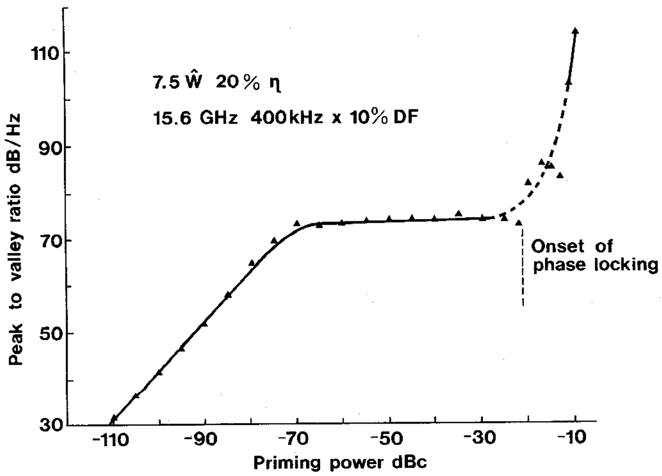


Fig. 4. The interline noise of a Read Impatt

As the priming frequency changes the coherency of the oscillator will also change; this is shown in Figure 5 for a constant priming power of -40 dBc. The fall off at high offset frequencies arises from the Q of the RF circuit and the displacement of the curves indicates that the small signal start frequency is ≈200 MHz below the final oscillator frequency. The frequency invariance of the PV ratio in the centre of the priming band indicates a constant residual phase error. By comparison the TEO exhibited interline noise that was consistent with a residual constant time (not phase) jitter. Similar measurements made on higher power oscillators are shown in Figure 4 as a function of external Q. In this case the start frequency is ≃600 MHz below the oscillator with only a weak dependence upon the Q; Figure 6. Measurements made on the double drift devices show broadly similar behaviour except that the switch on jitter is noticeably greater and the centre of the priming band is much closer (≃-50 MHz) to the oscillator frequency.

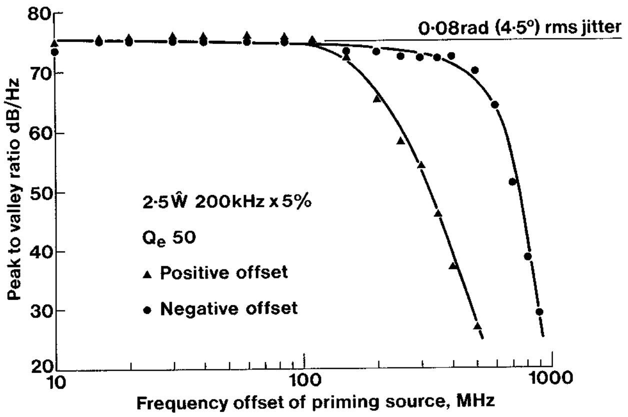


Fig. 5. The interline noise of a Read Impatt

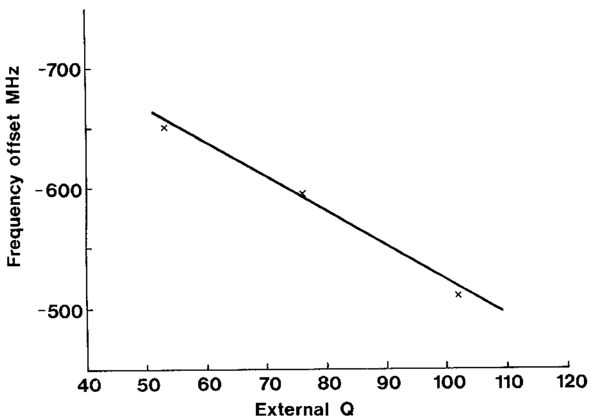


Fig. 6. The small signal frequency offset

DISCUSSION

The experiments described above have shown that the Read Impatt is ideally suited to short pulse fast rise time applications over wide temperature ranges. If coherent operation is a requirement of a radar system, then depending upon the degree of coherence required, phase priming can be a very attractive and efficient mode of operation needing very low synchronising powers.

These differences between the TEO and the Impatt can be explained readily by considering the admittance change between small and large signal operation. The observed delays and jitters lead to RF growth rates of approximately 5 and 0.25 dB/cycle (80 and 4 dB/ns) for the Read and TEO respectively[2]; which can explain the observed differences in the PV spectrum. The poorer performance of the TEO is indicative of a low RF growth rate at small signal strengths indicating that the small signal negative resistance is not significantly greater than the large signal resistance which is conjugately matched to the load. As a consequence of this lower RF growth rate external control of the starting conditions becomes easier and phase priming is more successful, requiring lower power levels and giving greater PV ratios. This appears to be a general result in that the best phase primed oscillator performance for coherent operation is obtained from those devices which have the poorer switch on characteristics. Unfortunately readily tractable models do not exist for the TEO which limits analysis but it is possible to use analytic models for the Impatt. We have used a model proposed by Statz et al[3] and incorporated into this the effects of space charge flow in the avalanche zone as proposed by Statz and Wallace[4]. The results of this analysis show that the small signal Q is much lower than the large signal Q and thus offers an immediate explanation for the lack of Q dependence of the priming bandwidth and small signal start frequency. This is in contrast to the TEO where the priming bandwidth is inversely proportional to the large signal Q. This change in Q arises since as the RF voltage increases both the conductance and the susceptance decrease, thus accounting for the lowered start frequency and the rapid RF growth rate.

As the Hi-Lo ratio is reduced the difference between the small and large signal admittances diminishes, with the result that the changes in both conductance and susceptance are smaller for the uniformly doped device. This is consistent with the observation that the uniformly doped double drift device has switch on characteristics between those of the Read Impatt and the TEO. These differences arise principally from the fact that in the higher efficiency Read device the greater voltage modulation and narrower avalanche zone leads to a sharper avalanche charge pulse which gives a considerable change in the large signal avalanche resonance frequency[3]. Typical values of the normalised field parameter are 3.5 and 2.0 for the Read and uniformly doped devices respectively, and the ratios of large to small signal Qs are typically 5 and 2. The analysis also indicates that for a finite bias current risetime the oscillator must switch on at a current well below the final operating current if there is to be sufficient negative conductance to promote growth of the RF signal with start frequencies below the final frequency. If an extremely rapid current risetime could be achieved (<<1 ns) then the start frequency would be above the oscillator frequency since in this case the susceptance would increase as large signal conditions were approached.

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